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Method and apparatus for downhole activated wellbore completion

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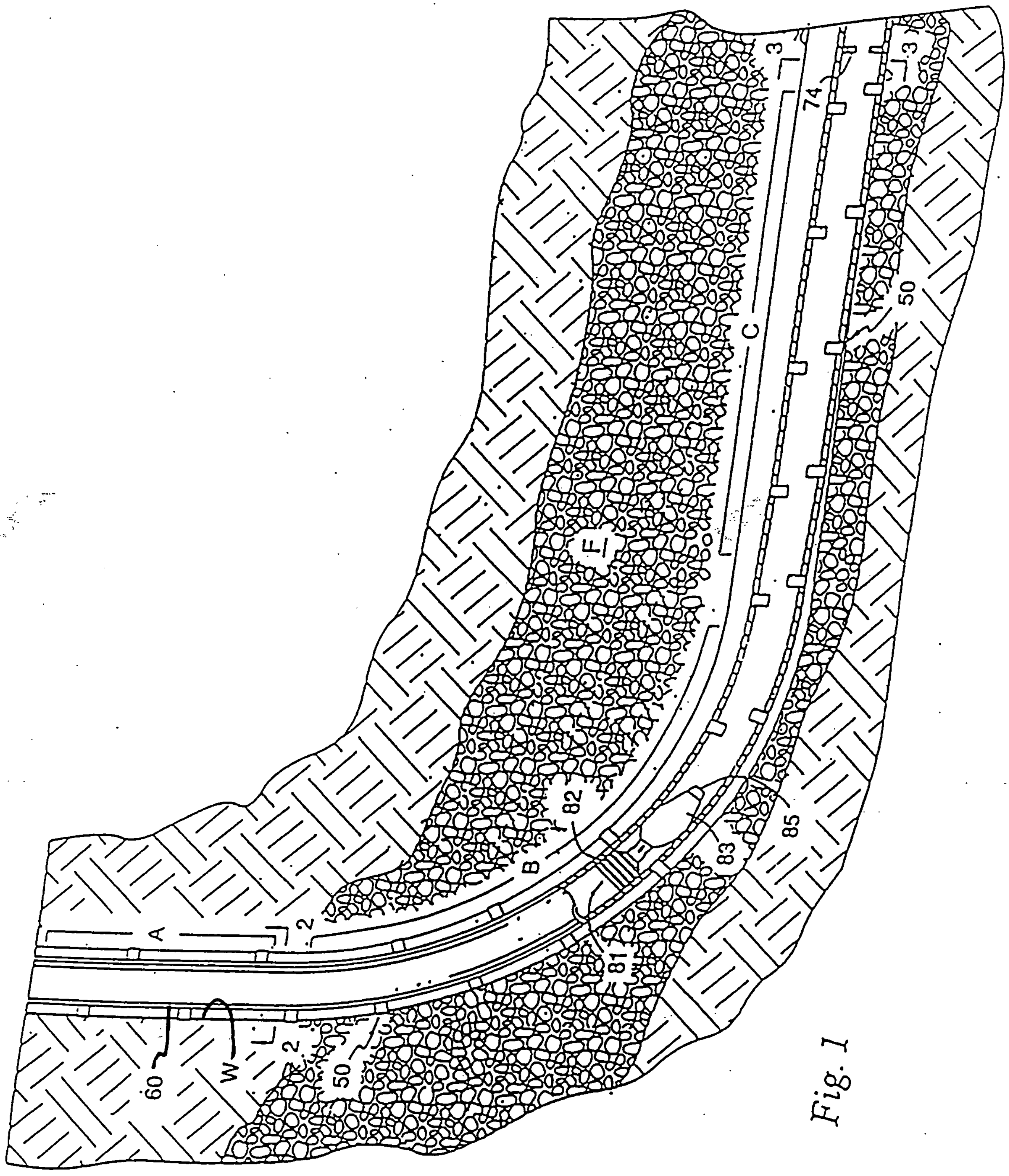

Fig. 1

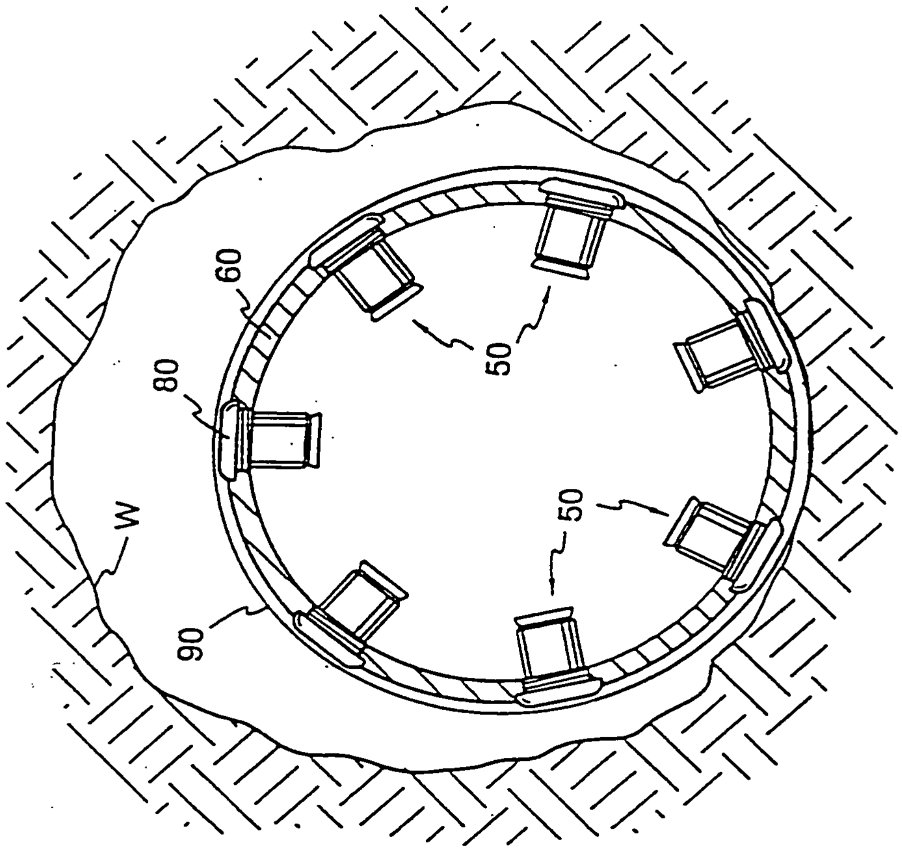

Fig. 3

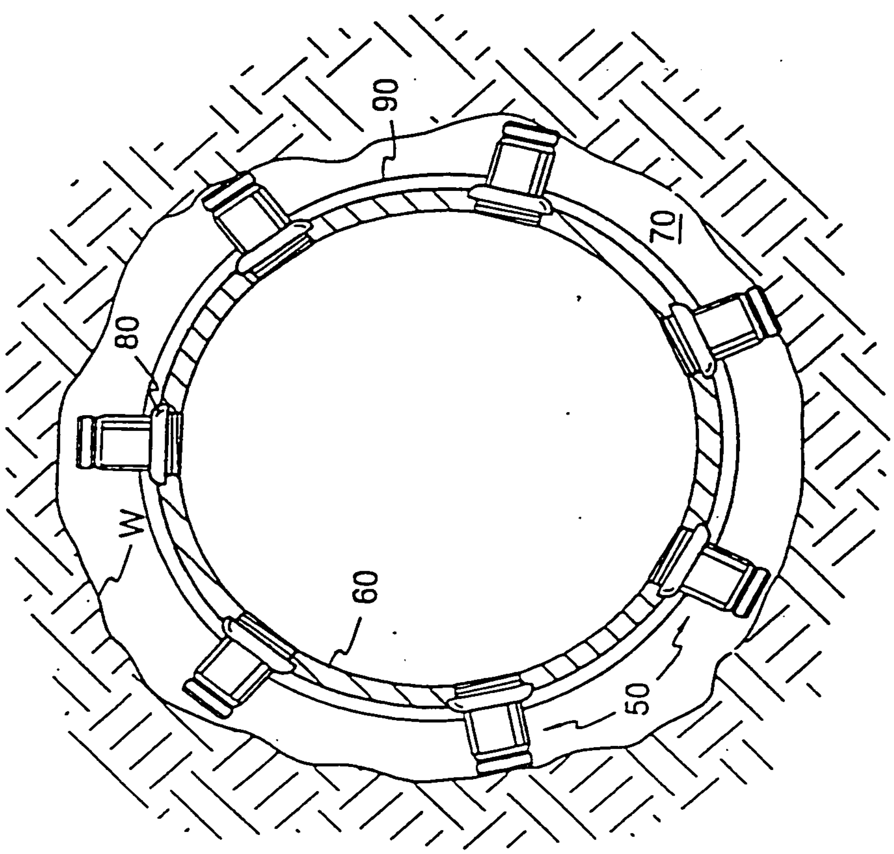

Fig. 2

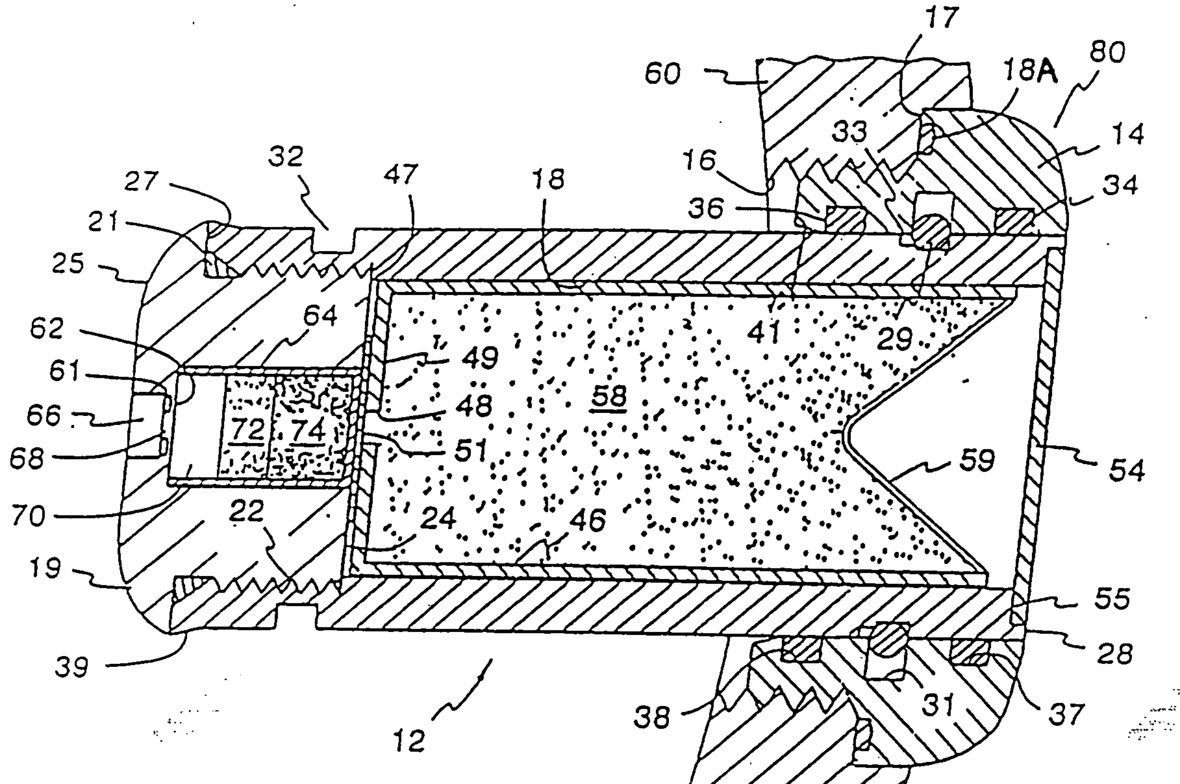

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Fig. 4

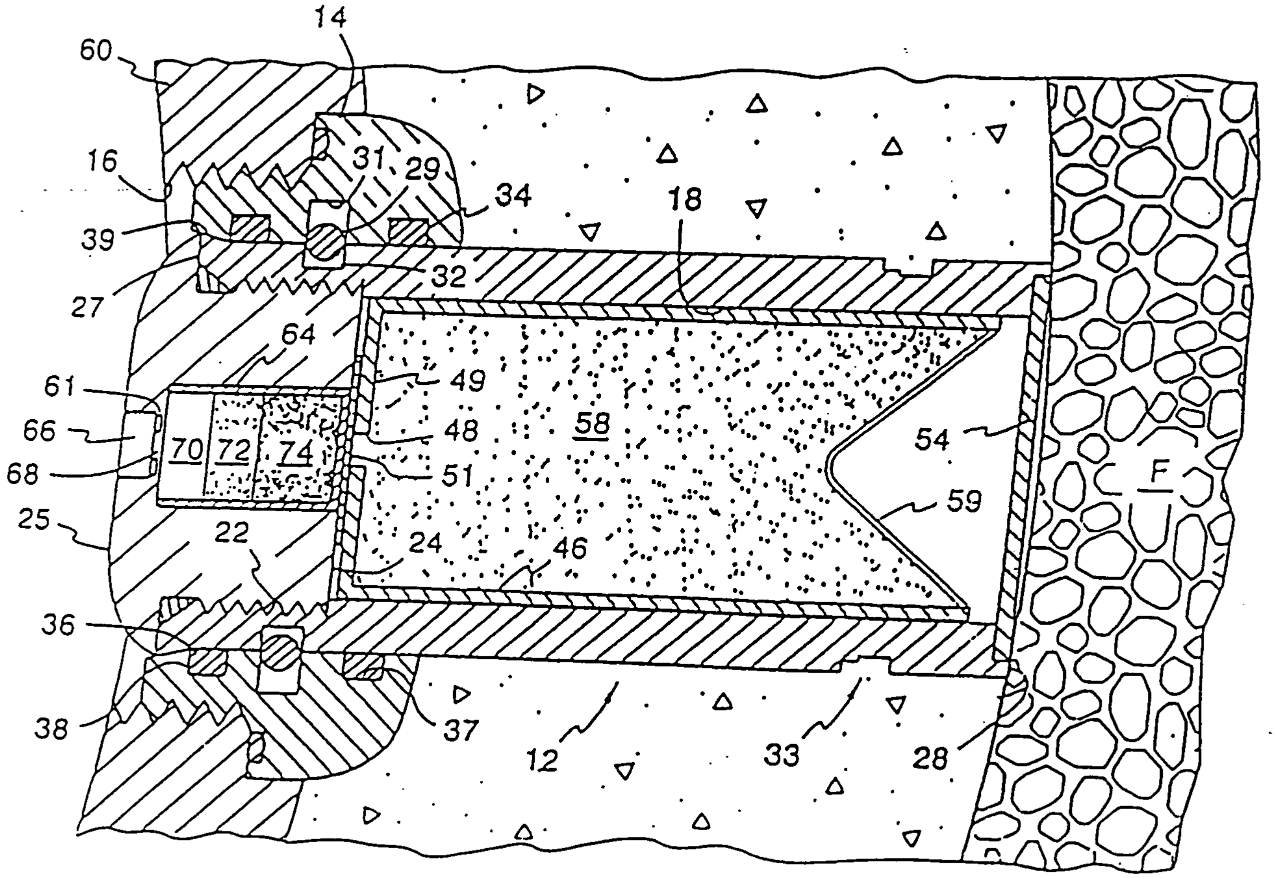

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Fig. 5

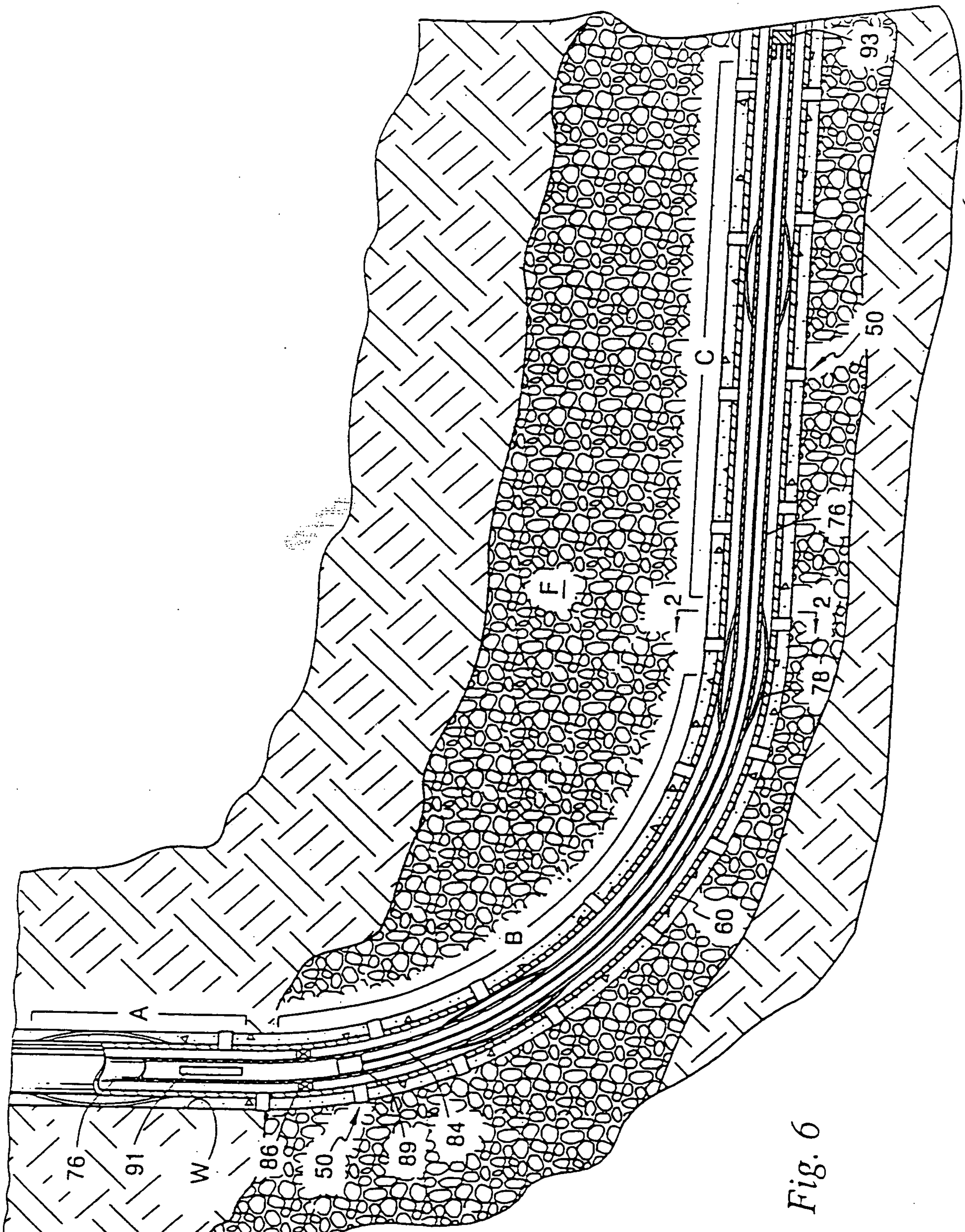

Fig. 6

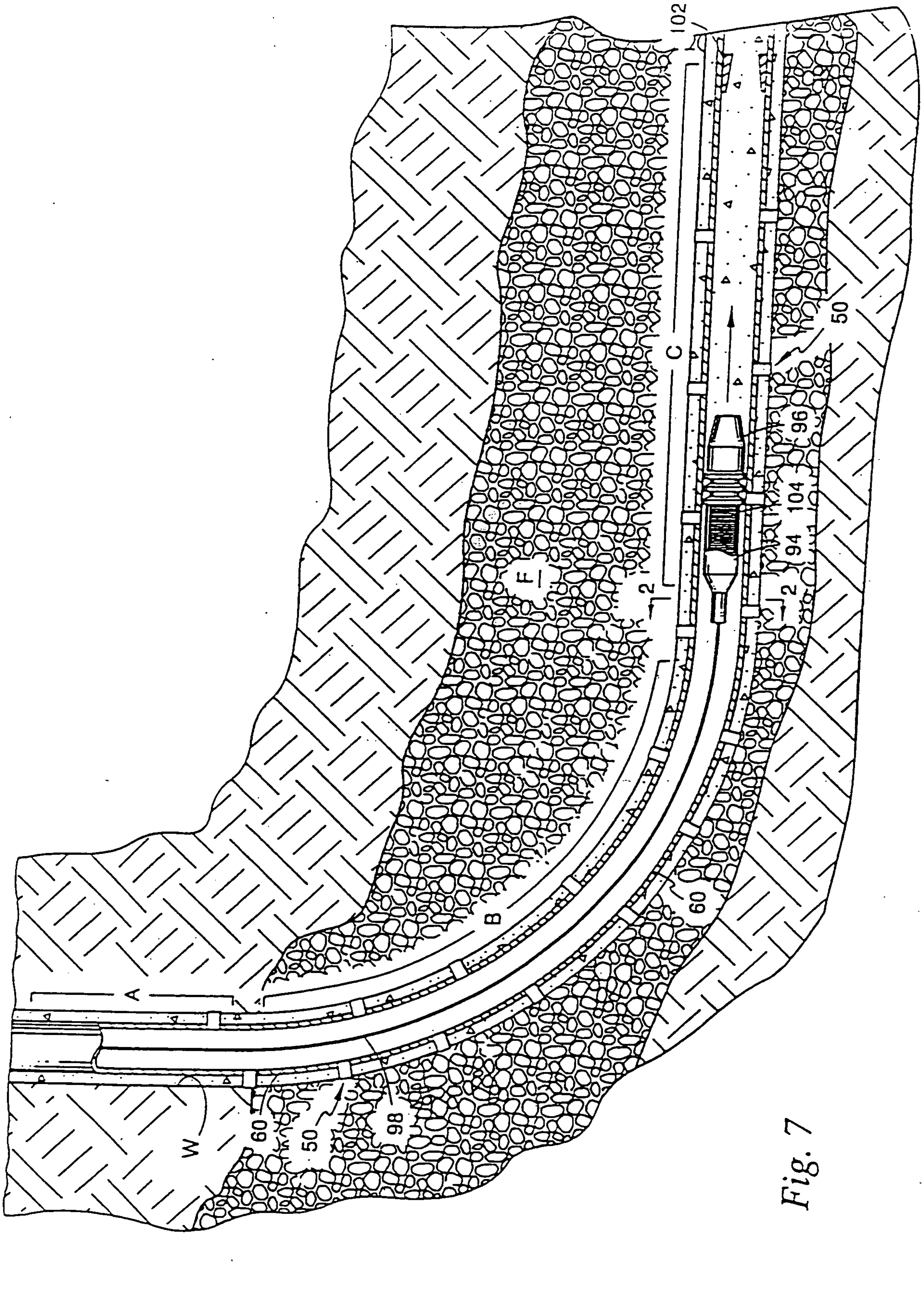

Fig. 7

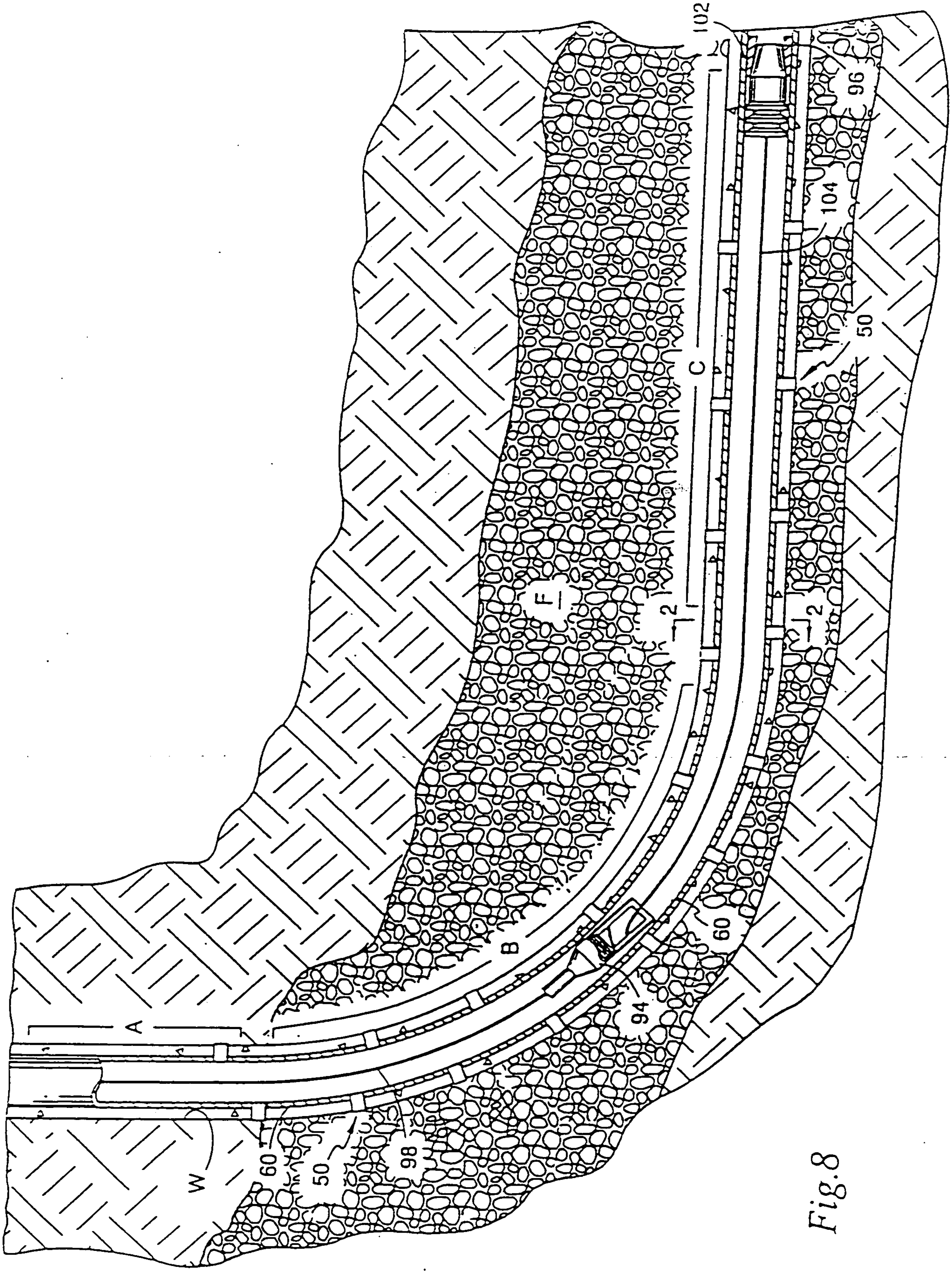

Fig.8

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METHOD AND APPARATUS FOR DOWNHOLE ACTIVATED WELLBORE COMPLETION

Field of the Invention

This invention relates to completing a well traversing earth formation in a borehole and more particularly to detonating a fluid flow device by means of a pressure wave to open communication between casing pipe and an earth formation.

Background of the Invention

In the process of establishing an oil or gas well, the well is typically provided with an arrangement for selectively excluding fluid communication with certain zones in the formation to avoid communication with undesirable fluids. A typical method of controlling the zones with which the well is in fluid communication is by running well casing down into the well and then sealing the annulus between the exterior of the casing and the walls of the wellbore with cement. Thereafter, the well casing and cement may be perforated at preselected locations by a perforating device or the like to establish a plurality of fluid flow paths between the pipe and the product bearing zones in the formation. Unfortunately, the process of perforating through the casing and then through the layer of cement dissipates a substantial portion of the energy from the perforating device and the formation receives only a minor portion of the perforating energy.

Additionally, when completing horizontal borehole sections in a well, whether cased or in open holes, it is often a problem getting perforating apparatus into the horizontal section because the gravity factor may not be sufficient to assist in running the equipment and friction

between the equipment and borehole walls or pipe further hinders such operations. For this same reason it is difficult in many cases to run casing into such a well, and when casing is installed, the typical bow spring centralizers are ineffective and it is difficult to center the casing in the borehole in order to cement the casing.

Accordingly, it is an object of the present invention to provide a method and apparatus for opening a fluid flow path between casing and the formation in a wellbore which overcomes or avoids the above noted limitations and disadvantages of the prior art.

It is a further object of the present invention to provide a method and apparatus for perforating a wellbore wherein a casing string is centered in the wellbore to provide for effective cementing of the casing even when installed in a horizontal borehole, and also where perforating charges are directed into the formation without penetrating a casing pipe.

It is yet another object of the present invention to provide a method and apparatus for perforating a wellbore wherein perforating charges are conveyed into the wellbore on a pipe string and are detonated by a pressure wave or pulse which is produced by equipment run into the wellbore separately from the pipe string.

Summary of the Invention

The above and other objects and advantages of the present invention have been achieved in the embodiments illustrated herein by the provision of an apparatus and method for positioning explosive charges in a wellbore wherein the charges are arranged to be detonated by a pressure or shock wave, and also positioning a pressure wave producing device in the wellbore which device is separated from the charges.

Additionally, the charges are placed in extendable pistons mounted in a casing string and the pressure wave producing device is run into the casing string in a separate operation. The casing may also then be cemented before the charges are detonated. By placing the charges in pistons extendable from the casing string, the charges are directed into the formation without passing through the casing and/or cement.

In one embodiment, the system comprises a piston for being mounted in an opening in the peripheral wall of the pipe and for extending generally radially outwardly from the pipe to contact the wall of the wellbore wherein the piston includes an explosive device therein. A deploying device deploys the piston from a retracted position which is generally within the maximum exterior profile of the pipe to an extended position wherein the piston extends generally radially from the opening to contact the wall of the wellbore. A detonation device is then positioned in the wellbore for detonating the explosive device in the piston while the piston is in its deployed position against the wall of the formation so as to perforate the formation by an explosive proximate to the formation. The piston when extended serves to center the pipe in the borehole and is substantially clear of the inner bore of the pipe to render the bore of the pipe full open.

Brief Description of the Drawings

Figure 1 is a cross-sectional view of a wellbore traversing earth formations with a casing string arranged therein and spaced from the walls of the wellbore by a plurality of downhole activated pistons which are shown being activated to an extended position and which embody features of the present invention.

Figure 2 is an enlarged cross-sectional end view of the casing taking along lines 2-2 in Figure 1, wherein the centralizers are shown extended to center the casing string in the wellbore.

Figure 3 is a cross-sectional end view similar to Figure 2 prior to the casing being centralized and with the downhole activated centralizers in the retracted position.

Figure 4 is an enlarged cross-sectional view of a centralizer piston having a detonation device and shaped charge positioned therein, with the piston shown in a retracted or running-in position relative to the casing wall.

Figure 5 is an enlarged cross-sectional view of the centralizer piston of Figure 4 in an extended position wherein the outer end of the piston is in contact with an earth formation.

Figure 6 is a cross-sectional view of a wellbore showing a casing centralized in a borehole by pistons in an extended position and further showing a pressure wave generating device positioned in the casing by means of a pipe string.

Figures 7 and 8 show cross-sectional views of a wellbore having an alternative system for producing a pressure wave in a casing string for detonating perforating charges.

Detailed Description of the Preferred Embodiments

Referring first to Figure 1 of the drawings, a wellbore W is shown having been drilled into the earth formations such as for the exploration and production of oil and gas. The illustrated wellbore W includes a generally vertical section A, a radial section B leading to a horizontal section C. The wellbore has penetrated

several formations, one of which may be a hydrocarbon-bearing zone F. Moreover, the wellbore W was drilled to include a horizontal section C which has a long span of contact with the formation F of interest, which may be a hydrocarbon-bearing zone. With a long span of contact within a pay zone, it is likely that more of the hydrocarbon present will be produced. Unfortunately, there are adjacent zones which have fluids such as brine that may get into the production stream and thereafter have to be separated from the hydrocarbon fluids and disposed of at additional costs. Accordingly, fluid communication with such adjacent zones is preferably avoided.

To avoid such communication with nonproduct-bearing zones, wellbores are typically cased and cemented and thereafter perforated along the pay zones. However, in the highly deviated portions of a wellbore such as the radial section B and the horizontal section C of the wellbore, the casing tends to lay against the bottom wall of the wellbore, thereby preventing cement from encircling the casing and leaving a void for wellbore fluids such as brine to travel along the wellbore and enter the casing far from the formation from which it is produced. In the illustrated wellbore W, a casing string or liner 60 has been run therein which is spaced from the walls of the wellbore by a plurality of downhole activated pistons generally indicated by the number 50, which serve to centralize the casing. The downhole activated pistons or centralizers 50 are retracted into the casing 60 while it is being run into the wellbore as is illustrated by the centralizers 50 in Figure 1 which are ahead of an activator or pusher 82. Once the casing 60 is suitably positioned, the centralizers 50 are deployed to project outwardly from the casing as illustrated behind the activator or in Figure 1. The centralizers 50 move the casing from the

walls of the wellbore if the casing 60 is laying against the wall or if the casing is within a predetermined proximity to the wall of the wellbore W. This movement away from the walls of the wellbore will thereby establish an annular free space around the casing 60. The centralizers 50 maintain the spacing between the casing 60 and the walls of the wellbore W while cement is injected into the annular free space to set the casing 60. The pistons, however, are latched in an extended position and will thereby maintain the casing 60 centered even if the casing is not cemented.

The centralizers 50 are better illustrated in Figures 2 and 3 wherein they are shown in the extended and retracted positions, respectively. Referring specifically to Figure 2, seven centralizers 50 are illustrated for supporting the casing 60 away from the walls of the wellbore W although only four are actually shown contacting the walls of the wellbore W. It should be recognized and understood that the centralizers work in a cooperative effort to centralize the casing 60 in the wellbore W. The placement of the centralizers 50 in the casing 60 may be arranged in any of a great variety of arrangements. In particular, it is preferred that the centralizers 50 be arranged to project outwardly from all sides of the periphery of the casing 60 so that the casing 60 may be lifted away from the walls of the wellbore W no matter the rotational angle of the casing 60. It is also preferred that the centralizers 50 be regularly spaced along the casing 60 so that the entire length of the casing 60 is centralized. The distance between centralizers and their radial orientation on the casing will vary depending upon the circumstances of a particular completion. For example, it is conceivable that the centralizers may be provided only in one radial orientation, or only at the ends of a

section of casing. In Applicants' U.S. patent US-5346016, incorporated herein by reference, various arrangements are shown for mounting centralizer pistons in the wall of a pipe string.

Referring again to Figures 2 and 3, the seven illustrated centralizers 50 are evenly spaced around the casing 60. As the casing is centralized, an annular space 70 is created around the casing within the wellbore. The casing 60 is run into the wellbore with the centralizers 50 retracted as illustrated in Figure 3 which allows substantial clearance around the casing 60 and permit the casing 60 to follow the bends and turns of the wellbore W. Such bends and turns particularly arise in a highly deviated or horizontal hole. With the centralizers 50 retracted, the casing 60 may be rotated and reciprocated to work it into a suitable position within the wellbore. Moreover, the slim dimension of the casing 60 with the centralizers 50 retracted (Figure 3) may allow it to be run into wellbores that have a narrow dimension or that have narrow fittings or other restrictions.

In Figures 2 and 3 and in subsequent figures as will be explained below, the centralizers 50 may present small bulbous portions 80 on the outside of the casing 60. It is preferable not to have any dimension projecting out from the casing to minimize drag and potential hangups while moving the string. However, as will be discussed below, the bulbous portions 80 are utilized in some embodiments especially in smaller diameter casings such is often used in horizontal holes when they are cased. It should also be recognized that the bulbous portions 80 are rounded to slide better along the walls of the wellbore and that the casing string 60 will include collar sections 90 that will extend out radially farther than the bulbous portion (see Figure 3). Thus, the collar sections 90

present the maximum outer profile of the casing string even when the bulbous portions are present. The outward projection of the retracted centralizers 50 being within the maximum outer profile of the casing string 60 is believed to minimize any problems of running the casing.

Referring again to Figure 1, a deploying device or pusher 82 which moves from the top of the casing to its bottom end is shown positioned within the horizontal curved section B of the casing string. The deploying device 82 is sized to push the pistons 50 from a retracted to an extended position. It is noted that the centralizers or pistons 50 behind or to the left of the pusher 82 are in an extended position having been engaged by the tapered nose portion 85 of the pusher. The tapered portion 85 engages the inner ends of the pistons and pushes them outwardly as the piston travels until the body portion 83 has passed the piston whereupon the piston will be fully extended and locked into an extended position as will be hereinafter described. The centralizers in front of the pusher 82 are still in a retracted position and consequently the horizontal portion C of the casing in front of the pusher is shown lying on the bottom side of the borehole. The upper vertical section A and radial section B are shown centered in that the pistons 50 have been deployed to an extended position. The activator device shown in Figure 1 is a pumpable activator or deploying device having a tail pipe 81 which extends rearwardly from the main body portion 83 and seals the rear end of the device to the inside of the casing so that the device may be pushed down through the casing 60 by the application of hydraulic pressure. In addition, the activator may be run into the casing string on the end of a pipe string such as a drill pipe or coiled tubing wherein force is applied to the pipe string and thus to an activation device to engage and push out or extend

the pistons 50.

The centralizers or pistons may take many forms and shapes as is illustrated in Applicants' U.S. patent US-5228518, incorporated herein by reference. In the present application, the piston or centralizer 50 is shown in Figures 4 and 5 as including an explosive charge for perforating formations in the borehole. Referring first to Figure 4, the centralizer 50 has a cylindrical or substantially cylindrical barrel portion or piston 12 which is slidably received in a bore in button 14. The button 14 is threadedly received within a tapped hole 16 which extends transversely through the wall of casing 60. A bulbous or rounded outer portion 80 extends outwardly slightly beyond the outside wall of the casing 60 but only to provide an adequate seat for the button 14 in thin wall smaller diameter casing and is constructed so that the outer extension of the bulbous portion 80 does not exceed the maximum profile of the pipe string which would normally be represented by the outside diameter of collars 90 in the casing string. The button 14 has a shoulder 17 formed at the base of the bulbous outer portion 80 that provides a surface for seating within a mating recessed surface at the outer end of the threaded hole 16 in the casing wall. The shoulder 17 forms a surface on the button which fits against the mating surface at the outer end of hole 16. An O-ring 18A is arranged within a groove on the shoulder 17 to provide a seal between the shoulder 17 and a face at the end of hole 16. The button 14 is arranged so that its inner end does not extend into the interior of the casing 60. The piston 12 is arranged for axial movement through the button 14 from a retracted position (Figures 3 and 4) to an extended position (Figures 2 and 5). The piston 12 and the button 14 are mounted into casing 60 so

that their axis are collinear and directed radially outwardly with respect to the axis of the casing 60. The piston 12 includes a plug 19 secured in an interior bore or passageway 18 in the piston by screw threads 22. An annular sealing ring 21 is positioned between the plug 19 and the inner end of piston 12. The piston 12 shown in Figures 4 and 5 also serves as a housing for a perforating device. The plug 19 is called an initiator plug in that it carries a device for initiating detonation of a shaped charge in the piston. The plug 19 does not fill the entire passageway 18 but is rather approximately the thickness of the casing 60. The plug 19 further includes a rounded inner end face 25 and a flat distal end face 24. The rounded surface 25 on the inner end of plug 19 is provided for facilitating the use of a deploying device to push the centralizer 50 into an extended position.

The distal end 28 of the piston 12 may be chamfered or tapered inwardly to ease the installation of the piston 12 into the button 14. The piston 12 is mounted in a central bore in the button 14 which is preferably coaxial to the opening 16 in the casing 60 and is held in place by a snap ring 29. The snap ring 29 is located in a snap ring groove 31 milled in the wall of the interior bore of the button 14.

Piston 12 includes two radial piston grooves 32 and 33 formed in the exterior cylindrical surface of the piston 12. The first of the two piston grooves is a circumferential securing or locking groove 32 which is positioned adjacent the inner end 27 of piston 12 to be engaged by the snap ring 29 when the piston is fully extended. The second of the two grooves is a circumferential retaining groove 33 positioned adjacent the distal end 28 of the cylinder 12 to be engaged by the snap ring 29 when the piston is in the retracted or running

position as shown in Figure 4. As the piston 12 is illustrated in Figure 5 in the extended position, the snap ring 29 is engaged in the radial locking groove 32.

The snap ring 29 is made of a strong resilient material arranged to expand into the snap ring groove 31 when forced outwardly and to collapse when unsupported into the grooves 32 and 33 when aligned therewith. The snap ring 29 is resilient as noted above so that it can be deflected deep into the snap ring groove 31 to slide along the exterior of the piston 12 and allow the piston 12 to move from the retracted position to the extended position. The snap ring 29 must also be strong to prevent the piston 12 from moving unless a sufficient activation force is applied to the piston 12 to deflect the snap ring 29 out of the retaining groove 33 into the snap ring groove 31 to permit the piston 12 to move through the snap ring to the extended position. The piston grooves 32 and 33 have a shape that in conjunction with the snap ring 29 allows the piston 12 to move in one direction but not the other. In the direction in which the snap ring 29 allows movement, the snap ring 29 requires an activation or deploying force of a certain magnitude before it will permit the piston 12 to move. The magnitude of the activation or deploying force depends on the spring constant of the snap ring 29, the relevant frictional forces between the snap ring 29 and the piston 12, the shape of the piston groove, and other factors. A particular arrangement of snap ring and grooves is shown in greater detail in Applicants' U.S. patent US-5346016, incorporated herein by reference.

Once the casing 60 is positioned in the wellbore for permanent installation, the pistons are deployed to the extended position. The deploying method provides a deploying force on the inner end of each piston to overcome

the resistance of the snap ring in the retaining groove 33 and cause the snap ring 29 to ride up and out of the retaining groove 33 whereupon the snap ring 29 is pushed up into the snap ring groove 31 within the button 14. This allows the piston to move out into the annular space of the wellbore. Once the piston encounters the wellbore wall, it will then lift the casing off of the wellbore to centralize the casing until such time as the snap ring 29 aligns with and expands into the locking groove 32. The pistons should be of such a length that the pistons can be fully deployed to the locking groove 32 while giving the maximum amount of centralization. Once the pistons are fully deployed, the inner surface 25 on the plug 19 will be substantially clear of the casing bore for all practical purposes, and the casing bore should be substantially full opened.

The button 14 further includes a sealing arrangement to provide a pressure tight seal between the piston 12 and the button 14. In particular, the button 14 includes two O-rings, 34 and 36, which are positioned on either side of the snap ring 29 in O-ring grooves 37 and 38, respectively. The O-rings 34 and 36 seal against the exterior of piston 12 to prevent fluids from passing from one side of the casing wall to the other through the bore of the button 14. The O-rings 34 and 36 must slide along the exterior of the piston 12 passing the piston grooves 32 and 33 while maintaining the pressure tight seal. Accordingly, it is a feature of the preferred embodiment that the spacing of the O-rings 34 and 36 is such that as the piston 12 moves through the bore of the button 14 from the retracted position to the extended position, one of the O-rings 34 or 36 is in sealing contact with a smooth exterior surface of the piston 12 while the other may be opposed to one of the piston grooves 32 and 33.

The piston 12 further includes an outwardly

tapered enlarged diameter peripheral edge 39 on its inner end 27, which edge 39 is larger than the bore in button 14 that receives the piston 12. Thus the edge 39 serves as a stop against the button 14 to limit the outward movement of the piston 12. The inside face of button 14 includes a chamfered edge 41 for engaging the outwardly tapered peripheral edge 39 on the piston when the inner end 27 of the piston is approximately flush with the inner end face of the button 14. Therefore, while the extended piston 12 is recessed into the button 14 and clear of the interior bore of the casing 60, the inwardly facing rounded surface 25 of the initiator plug extends slightly into the bore of the casing for purposes to be described so that it is substantially clear of the bore to render the casing bore fully open to permit passage of the deploying device 82 or other similar device such as packers or the like that would be passed through the bore of a casing string.

As noted above with respect to Figures 1 to 3, the centralizers 50 are initially arranged in the retracted position so that the casing 60 can be run into the well without the drag and interference of the centralizers 50 extending outwardly. The snap ring 29 is engaged within the retaining groove 33 to hold the piston in the retracted position until the piston 12 is moved outwardly. Once the casing 60 is positioned in the wellbore for permanent installation, the pistons 12 are deployed to the extended position. A deploying arrangement as will be discussed below, provides a deploying force on the inner end of each piston 12 to overcome the resistance of the snap ring 29 in retaining groove 33 and cause the snap ring 29 to move into the snap ring groove 31 as the outer surface of piston 12 expands the snap ring outwardly. The deploying force further moves the piston 12 radially outwardly through the bore of button 14 so that the snap ring 29 rides over the

outer surface of piston 12 to engage the locking groove 32 and thereby secure the piston in an extended position. When extended, the inner end of the piston and the rounded end face 25 of the initiator plug 19 are substantially clear of the casing bore to render the casing fully open for running tools or equipment therethrough. The term full open bore within the context of oil field terminology, encompasses a situation such as the present wherein for all practical purposes equipment can be moved through the bore of a pipe unrestrictedly. In the present situation, the rounded end 25 of the plug 19 is designed to encroach into the bore approximately .14 inches (0.36 cm). When the piston is extended, this encroachment is further reduced when the deploying device 82 forces the piston outwardly and slightly deforms the rounded end face 25 of the plug 19. Any equipment which would be passed through a casing string bore would readily pass this end portion 25 when the centralizers are extended.

As illustrated in Figure 2 and 3, the casing 60 and centralizers 50 are selected based on the size of the wellbore W so that the pistons 12 may fully extend to the extended position and contact the borehole wall around most of the casing 60. Accordingly, during deployment of the piston 12 the deploying force is expected to move the piston 12 to its fully extended position wherein the snap ring 29 will snap into the securing groove 32 as the piston 12 moves to the fully extended position. The securing groove 32 has square edges so that the snap ring rides deep within the groove to prevent the snap ring from being expanded and thus to prevent the piston 12 from retracting back into the casing 60.

At about the same time that the snap ring 29 engages the securing groove 32, the outwardly tapered enlarged edge 39 of the piston 12 engages the chamfered

edge 41 of the button 14 to stop the outward movement of the piston 12. Accordingly, once the snap ring 29 snaps into the securing groove 32, the piston 12 cannot extend outwardly farther and cannot be retracted.

Still referring to Figure 4, the inner bore 18 of the piston 12 is shown having a shaped charge insert installed therein. The shaped charge insert includes a cup-shaped canister or carrier 46 which is sized to be press fit into the bore 18 of the piston 12. A locking compound is used to hold the canister 46 in the bore cavity of the piston. The carrier 46 is nested against a shoulder 47 in the piston bore 18, the shoulder 47 being the end of the threads 22 which are cut in the bore 18 of the piston at its inner end to receive plug 19. An ignition hole 48 is formed in the inner wall 49 of the cup-shaped carrier 46. A thin metal foil 51 is placed over the outer surface of hole 48 facing the plug 19. At the distal end of the piston 12, an outer end cap 54 is fitted within a recessed shoulder 55 and is held in place by its press fit and a locking compound. A shaped charge 58 is positioned in the canister 46 with a conical depression and metal liner 59 in the distal end of the face of the shaped charge facing outwardly.

The opposite inner end of the piston 12 has the plug 19 enclosing the inner end. The plug 19 has a cylindrical recess 62 which is formed from the inner side of the plug 19 for receiving a detonator shell or cup 64. The shell 64 is held in place within the recess 62 by means of a thread locking compound press fit or the like. On the rounded outer surface 25 of the plug 19 and central to the plug 19, a recess 66 is formed in the outer wall surface 25 opposite the recess 62 on the interior of the plug 19. The recess 66 may be for example 3/16 inch (0.48 cm) in diameter and approximately .040 inches (0.10 cm) deep to leave an integral rupture disc portion 68 formed between the recesses 62 and 66. The rupture disc may be on the order of .0275 inches (0.07 cm) thick. The shell 64 which is assembled within the recess 62 has provided within its interior bore a detonating system which is comprised of an air space 70, a primary charge comprised of a layer of lead azide 72, and a base charge comprised of a layer of RDX explosive 74. Typical priming charges are of lead azide, lead styphanate, diazodinitrophenol, mercury fulminate and nitromannite. Mixtures of diazodinitrophenol potassium chlorate, nitromannite/diazodinitrophenol and lead azide/lead styphanate or a layer of a mixture of lead styphanate can be placed over lead azide.

An alternative arrangement of rupture disc in Figure 5 includes a circular groove 61 formed inwardly into the plug 19 on either side of the disc 68. In order to accommodate this groove 61, the rupture disc 68 is made thicker so as not to unnecessarily weaken the integrity of the barrier 68 that protects the detonator shell 64. By undercutting the circular groove or rim 61 around the circumference of the rupture disc 68, the disc 68 will yield more predictably than by relying solely on normal yield of the metal between the recesses 66 and 62. This in turn provides initiation reliability to the pressure wave

detonation process. Also a thicker disc 68 can be provided between the recesses 66 and 62 to protect the detonator from inadvertent activation by movement of a piston activating or extending device 82 through the casing bore.

In Figure 5 of the drawings, the centralizing piston 12 is shown having been moved to an extended and locked position wherein the distal end 28 of the piston is in contact with the bore hole wall. A deploying device 82 such as is shown in Figure 1 has been moved through the interior bore of the casing string to contact the outer surface 25 of plug 19 on the inner end of the piston. As the deploying device 82 passes the position in the casing string where the cylinder is positioned, the cylinder is forced outwardly with sufficient force to override the restraining effect of the snap ring 29 in the retaining groove 33. This overriding force causes the snap ring to move upwardly and expand outwardly into the groove 31 as it expands over the outer surface of the piston 12. The piston continues its movement until the tapered enlarged portion 39 on piston 12 abuts the mating chamfered surface 41 on the button 14 whereupon the piston 12 is positioned so that the snap ring 29 retracts into the locking groove 32 to hold the extended cylinder 12 in a predetermined fixed position. At this point, the deploying device 82 (Figure 1) will have passed the extended piston 12 and proceeded downwardly through the casing string.

The plug 19 at the inner end of the piston 12 is arranged so that it extends slightly into the interior bore of the casing string so that as the deploying device 82 passes the plug 19, the rounded surface 25 guides the deploying device past the plug 19. The plug 19 is of a material soft enough to be slightly deformed by the passage of the deploying plug and also is sized so that the rubber seal portion 81 at the rear of the deploying plug is

deformable to a certain extent to permit its passage. The plug 19 is arranged so that the deformation of the curved outer surface 25 does not rupture the rupture disc portion 68 which is formed between the outer cavity 66 and the inner cavity 62 of the detonating device. It is also noted, that the explosive material 72 is spaced away from the end of the plug 19. Thus the passage of the deploying device 82 through the interior bore of the casing 60 will not cause sufficient distortion of the plug 19 to bring the rupture disc 68 into contact with the explosive material 72. Once the piston is extended and locked in its predetermined fixed position as shown in Figure 5, the perforating apparatus is now in a position to permit perforation of the formation which the wellbore traverses. It is noted, that alternatively the pistons 12 may be extended by the application of hydraulic pressure to the interior of the casing pipe string which provides a force that impinges on the inner end of the piston to move the pistons outwardly.

It is to be noted that one particular advantage of the apparatus described herein is that the centralizing piston and a button 14 which guides the piston, when provided, may be assembled within the casing string at some time just before the casing is run into the wellbore W. Accordingly, the handling of the casing pipe up to the point that it is being installed in the wellbore is not subjected to the danger which might be caused by having the explosive devices installed during shipping and handling of the casing prior to its installation. It is also to be noted that there is no device present within the system thus far described to initiate the explosive device within the piston so that such handling in the configuration described above is considered safe and will not unnecessarily endanger the personnel who are installing the

devices in the casing or installing the casing within the wellbore.

Referring now to Figure 6 of the drawings, the casing 60 is shown having been run into a well. The centralizers are shown having been extended by means of a pumpable activator device 82 such as shown in Figure 1 or by the application of hydraulic pressure to the casing string at the surface. This is accomplished by closing a valve at the base of the casing string and applying the necessary activation or deploying force required to move the pistons from the retracted position to the extended position. Accordingly, pumps or other pressure generating mechanism would provide the necessary deploying force for the pistons.

Once the casing has been centralized within the wellbore, an annulus of cement can be injected and set around the entire outer periphery of the casing, over some appropriate interval of casing, to seal the casing from the formation. As suggested by the present invention, the casing string with the centralizer system as described is arranged so that in those portions of the wellbore where it is desired to have a centralizing only function for the centralizers, the centralizers are not configured so as to provide a perforating function. However, within a zone opposite formation F as shown in Figure 6, where it is desirable to open the casing to permit the recovery of fluids from the formation into the casing string and to perforate the formation, the centralizers are of the embodiment shown in Figures 4 and 5 which include a shaped charge device or the like for perforating the formation to be produced.

In the initial installation of the casing within the wellbore, it is important to note that the centralizers which are not extended permit the casing to be rotated and

reciprocated to work past tight spots or other interferences in the hole. These retracted centralizers 50 also do not interfere with the fluid path through the casing string so that fluids may be circulated through the casing to clear cuttings from the end of the casing string. Also the casing interior can be provided with fluids that are less dense than the wellbore fluids, in the annular space, causing the casing string to float. Clearly, the centralizers 50 of the present invention permit a variety of methods for installing the casing into its desired location in the wellbore.

Once the casing 60 is in a suitable position, the centralizers are deployed to centralize the casing. As discussed above, there are several methods of deploying the centralizers. Once the pistons are all deployed and the snap rings have secured them in the extended fixed position projecting outwardly toward the wall of the wellbore, the cement may be injected by well known techniques into the annulus formed by the centralizing of the casing within the borehole.

The cement around casing 60 may be allowed to set while the production string is assembled and installed into the casing. It is important to note that at this point in the process of establishing the well, the casing and wellbore are sealed from the formation. Accordingly, there is as yet no problem with controlling the pressure of the formation or with loss of pressure control fluids into the formation. In a conventional completion process, the perforation string is assembled to create perforations in the casing adjacent to the hydrocarbon bearing zone. Accordingly, high density fluids are provided in the wellbore and the production string to maintain a sufficient pressure head against the affect of formation pressure to avoid a blowout situation. While the production string is

assembled and run into the well some of the wellbore fluids, in an overbalance condition, may be forced into the formation. Accordingly, the production string must be installed quickly to begin producing the well once the well has been perforated. However, with the present invention, such problems are avoided. Once the casing is set in place, the production string may be assembled and installed in the casing before the casing is opened and perforation of the formation is performed. If the production string is already in place in the well, adequate surface controls are already in place to prevent a blowout, so that the casing and production string can be in an underbalanced condition. Thus, production may begin when communication is established with the formation, such as by perforation. Accordingly, the well is brought on-line in a more controlled manner.

Figure 6 shows an apparatus and system for initiating the detonators within the detonator shell 64 (Figure 5) in the pistons, in order to fire the shaped charges and penetrate the formation. A small diameter pipe string such as production tubing 76 or coiled tubing is run into the interior of the casing string after the centralizers 50 are extended. The casing may or may not be cemented in place. A detonating cord 84 may be pre-installed in the lower end of the tubing string 76 and run into the well with the tubing string. Alternatively, the tubing string may be located in the casing string and then the detonating cord is run into the tubing string. In the latter case, in order to set the detonating cord 84 in place, the bottom of the tubing string could be provided with a latching mechanism 93. After the tubing 76 is run into the casing string, a sinker bar with detonating cord trailing behind, can be lowered into the tubing string and latched inside of the tubing. Alternatively, a device can

be pumped to the latch 93 with a detonating cord trailing. A perforating head 89 would be run at the trailing, upper end of the detonating cord 84 to provide a means for initiating the detonating cord. The perforating head normally utilizes a detonator actuated by electrical, mechanical, or hydraulic means. Once the tubing is run, a production packer 86 can be set. At this time a sinker bar 91 can be dropped which would strike the perforating head and thereby initiate the detonating cord. Alternatively, a wireline can be used to operate the perforating head or otherwise initiate the detonating cord. Once the detonating cord is initiated, it results in the development and propagation of a pressure wave within the pipe string 76. This pressure wave is then communicated through the fluid in the pipe 76 and casing 60 to the plug 19 at the inner end of the cylinders 12. If necessary, the pipe string 76 may be centered in the casing by means of conventional centralizers 78. Centering the pipe string 76 in the casing string may be important in view of the importance of propagating a pressure wave to the cylinders 12 on all sides so that the force of this pressure wave is sufficient to rupture the disc 68 in the plug 19. This rupture of disc 68 will sequentially initiate the powders 72 and 74 within the shell 64 positioned in the plug 19. Tests have shown that initiation of the detonator will take place without the provision of an air space 70 in the shell 64 by locating powders adjacent to the ruptured disc 68. The amount of pressure required to rupture the disc is increased when the air space is eliminated, so that the powder contacts the disc; however, detonation does take place. It is believed that the principle behind the detonation is an adiabatic compression within the shell 64 which is sufficient to initiate the powders 72, 74 therein. Therefore, it appears to only be necessary to generate

sufficient pressure within the interior of the casing bore to cause the ruptured disc 68 to rupture which will thereby initiate the detonator housed within the shell 64. When a shaped charge is present in the piston 12, initiation of the detonator is communicated through the opening 48 within the carrier 46 to detonate the shaped charge 58. This detonation produces a penetrating force that is directly applied to the formation F so that all the outwardly directed energy of the shaped charge is applied to perforation and fracturing of the formation.

In the configuration shown in Figure 6, the smaller diameter pipe 76 housing the detonating cord, may be provided with slots or holes in the outside walls thereof to facilitate transmission of a pressure wave emanating from the detonating cord to the perforating cylinders 12. However, experiments have shown that a pressure wave may be propagated through the walls of solid pipe which is sufficient to initiate the detonators within the plug 19 on the cylinders 12. The system shown in Figure 6 with a production packer 86 set in place will permit the completion to take place with an under-balanced fluid in the pipe string, so that upon perforation of the formation F formation, fluids may be readily received into the casing string through the now open cylinder 12 and from there into the production tubing 76 for conveyance to the surface.

Referring now to Figures 7 and 8 of the drawings, an alternative system for detonating the perforators includes a pumpdown arrangement for positioning a detonating cord within the interior of a casing string. An important feature of this centralizing and perforating system is that the perforators are not functionally armed when they are installed in the casing string, nor when they are positioned in the borehole, in that an initiating

source is not provided. A means is thus provided for initiating the perforators after they are located within the wellbore. In this embodiment, a detonating cord is again provided to generate a pressure wave which in turn ruptures the protective membrane or disc 68 on the end of the plug 19 within the perforating cylinder 12, with such rupturing of the membrane causing the detonator explosives to fire. Firing of the detonator explosives will initiate firing of the shaped charge. The detonating cord 104 is carried in a housing 94 which is attached to a displacement plug 96. The plug 96 may be pumped down behind cement being injected into the annulus to isolate the casing string from the formation. The detonating cord 104 is shown in Figure 7 coiled up within the housing 94 which is releasably attached to the pumpdown plug 96. An electrical wireline or the like 98 which is attached to the housing 94 is pulled into the casing string through a stuffing box (not shown) at the surface. Once the displacement plug 96 and housing 94 reaches the bottom of the casing string, it lands in a seat 102 whereupon a pressure increase in the casing is registered at the surface to indicate that the plug has seated at the bottom of a casing string in the seat 102 and sealed off the end of the casing at least partially. The seat 102 provides a latching mechanism (not shown) for holding the seated plug 96 in place. Such displacement plugs and latching mechanisms are commonly used in cementing operations. Thereafter the wireline 98 is pulled upwardly as shown in Figure 8 to release the housing 94 from the displacement plug 96. The detonating cord 104 which is positioned within the housing and which is attached to the displacement plug 96 is then pulled out behind the upwardly moving housing 94 a sufficient distance to ensure that the detonating cord is positioned within the pipe string opposite the centralizer/perforators which are

to be activated by a pressure wave. The upper end of the detonating cord is attached within the housing 94 to an electrically operated detonator (not shown) on the end of the electric wireline 98. When the displacement plug 96 lands at the bottom and we know that all the cement in the pipe string is displaced, 24 to 48 hours is given for the cement to set up. After the cement has set up, an electrical current is passed from the surface through the wireline 98 for detonating cord detonation. Firing of the detonating cord generates a pressure wave within the casing pipe 60 which in turn impinges upon the rupture disc or membrane 68 in the end of piston 12 to fire the detonating mixtures 72, 74 within the detonator cup. This detonation in shell 64 passes energy through the opening 48 within the carrier 46 to initiate the shaped charge 58 within the cylinder 12. This in turn causes the shaped charge 58 to penetrate into the formation F and to develop a communication path between the interior of the casing string and the formation.

In the process of perforating the formation as described in the present invention, it is noted that the word "penetrating" is used to describe the process for opening a communication path into the formation. The reason that penetrating the formation is desirable is that the permeability of porous reservoir rock is usually reduced or plugged near the wellbore due to the leakage of drilling fluids into the first few inches of rocks surrounding the wellbore. This reduces permeability near the wellbore and is referred to as skin damage. In the present perforating technique, the shaped charges are not designed to punch a hole in the casing as in a normal perforating system, but rather to establish communication with the reservoir rock and to penetrate the rock itself with a fracturing and penetrating blast that extends

communication beyond the skin damage. Whereas normal shaped charges in a perforating system are positioned within the casing string and must therefore progress through the fluids within the casing string, the steel casing string wall, and then into the skin damaged portion of the reservoir. In the present system the shaped charge is positioned directly against the formation and thus a much greater portion of the energy developed by the shaped charge is applied to the formation rock itself.

It is readily appreciated that various other techniques could be developed for providing the placement of a detonating cord into the interior of either a casing pipe string or a production string in order to initiate the pressure wave described herein for detonating the perforation devices. For example, the detonating cord could be pumped in behind a pumpable plug or the like to position the detonating cord into a horizontal reach of pipe. In a vertical or nearly vertical pipe section, gravity would be sufficient to lower a detonating cord weighted on its lower end, into a pipe string. In addition, other methods could be used to develop a pressure wave for initiating the shaped charge. Also, it is readily seen that a variety of detonators might be used to initiate the explosion of the shaped charged within the centralizing cylinder 12. Therefore, while particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention as defined by the appended claims.

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Claims

1. A completion system for use in a borehole drilled into earth formations wherein it is desirable to establish a fluid communication path between the interior of a casing pipe string and an earth formation traversed by a borehole, comprising:

a pipe string in the borehole, said pipe string having portions thereof with extendible pistons mounted in the wall of said pipe string for movement between a retracted position within the pipe string and an extended position that moves a distal end of the piston toward the borehole wall;

explosive means within said pistons for making a flow path to the earth formation upon activation of the explosive means; and

activation means for being conveyed into said pipe string after said pistons in said pipe string are extended into contact with the borehole, to detonate said explosive means.

2. A completion system for use in a borehole drilled into earth formations wherein it is desirable to establish a fluid communication path between the interior of a pipe string in the borehole and an earth formation traversed by the borehole, comprising:

a pipe string for placement in the borehole;

explosive means carried by said pipe string into the borehole for making a flow path between the pipe string and the earth formations upon activation of said explosive means;

activation means for being conveyed into said pipe string after said explosive means is carried into the borehole on said pipe string, to a position that is spaced from said explosive means, said activation means

being operable to activate said explosive means; and means for operating said activation means.

3. The completion system of claim 1 or 2, wherein said activation means is comprised of a selectively operable pressure wave producing device which is positioned within said pipe string, which device, when operated, produces a pressure wave or pulse which activates said explosive means.

4. The completion system of claim 1, 2 or 3, which further includes detonator means adjacent said explosive means, said detonator means being detonated in response to a pressure wave produced in said pipe string.

5. The completion system of any preceding claim, wherein said explosive means includes a shaped charge explosive which is oriented to direct a major portion of its explosive force into the formation when said explosive means is activated.

6. The completion system of any preceding claim, wherein said activation means is a detonating cord which is positioned axially along the interior of said pipe string.

7. The completion system of claim 1, wherein said activation means is a detonating cord arranged to be operated when it is out of direct contact with said pistons when extended for providing a pressure wave upon operation thereof to activate said explosive means.

8. The completion system of claim 6, wherein said detonating cord is conveyed within a smaller pipe string which is positioned within said casing pipe string.

9. The completion system of claim 8, wherein said

smaller pipe string is a coiled tubing.

10. The completion of system of claim 8, wherein said smaller pipe string houses the detonating cord and wherein said smaller pipe string has openings in its outer wall to facilitate travel of a pressure wave emanating from said detonating cord through said openings into contact with explosive means carried in said casing pipe string, when said detonating cord is operated.

11. A method of perforating an earth formation traversed by a borehole to provide a fluid communication path between a borehole casing pipe string and the earth formation, comprising the steps of:

positioning perforating charges on the casing pipe string at the surface for insertion into the borehole on the casing pipe string;

positioning the casing pipe string in the borehole where formations are to be perforated; and

producing a pressure wave within the interior bore of the casing pipe string having the perforating charges positioned thereon, to detonate the perforating charges.

12. A method of perforating earth formations traversed by a borehole to provide a fluid communication path between a pipe string in the borehole and the earth formation, comprising the steps of:

running perforating charges into the borehole on the pipe string to a position in the borehole opposite a formation to be perforated;

after running the perforating charges into the borehole on the pipe string, in a separate operation running a pressure wave producing device into the pipe string; and

operating the pressure wave producing device to detonate the perforating charges.

13. The method of claim 11, further including the step of running a pressure wave producing device into the casing pipe string after the casing is positioned in the borehole where formations are to be perforated.

14. The method of claim 11, 12 or 13, further including positioning an elongated detonating explosive device in the pipe string after the pipe string is positioned in the borehole and activating the explosive device to produce a pressure wave within the pipe string to detonate the perforating charges.

15. The method of any of claims 11-14, and further including after positioning the pipe string with perforating charges in the borehole where formations are to be perforated and prior to detonating the perforating charges, injecting cement through the pipe string into a space between casing pipe and the formation and providing a time delay for the cement to set up.

16. The method of any of claims 11-15, wherein said perforating charges are positioned within pistons, which pistons are movably mounted within the side walls of portions of the pipe string, and further including moving the pistons from a retracted position substantially within the profile of the outside diameter of the pipe string to an extended position wherein one end of the pistons is extended toward contact with the earth formations.

17. The method of claim 16, wherein said pistons are moved to an outwardly extended position by moving a deploying device through the inside of the pipe string into contact with an inner end of the retracted pistons to slidably move the pistons through the wall of the pipe to an outwardly extended position and latching the piston in the outwardly extended position.

18. The method of claim 15, further including, before producing a pressure wave in the pipe string to detonate the perforating charges pushing a displacing device through the pipe string to displace cement from the pipe string and running a pressure wave producing device into the pipe string on the displacing device.

19. The method of claim 15, wherein said pressure wave producing device is connected to a wireline electrical cable, and further including energizing the wireline electrical cable from the surface to detonate the pressure wave producing device.

20. The method of claims 11 or 12, further including installing a percussion type detonator in proximity to the perforating charges which detonator is responsive to the produced pressure wave to detonate the perforating charge.

21. The method of claim 20, further including positioning perforating charges on a pipe and running the pipe into the borehole to the position to be perforated, and after running the pipe into the borehole, separately running the pressure wave producing device into the pipe.

22. A method of perforating a borehole drilled into earth formations wherein it is desirable to provide a fluid communication path between an earth formation and a pipe string, comprising:

positioning perforating charges in the borehole, said perforating charges being arranged for detonation in response to a pressure pulse;

separately positioning a pressure wave producing device in the borehole in proximity to the perforating charges but physically spaced therefrom;

operating the pressure wave producing device to

generate a pressure pulse to initiate detonation of the perforating charges.

23. The method of claim 22, wherein the perforating charges are housed in pistons transversely mounted within the wall of the pipe for movement between retracted and extended positions, applying a force to an inner end of the piston within the pipe to move an outer end of such pistons toward contact with the earth formations to be perforated and fixing the pistons in an extended position to centralize the pipe in the borehole.

24. The method of claim 23, further including, prior to detonating the perforating charges, injecting cement through the pipe into a space between the formations and the pipe, and allowing the cement to set up.

25. The method of claim 23, wherein the force for extending the pistons into contact with the formations is provided by moving a plunger through the pipe to physically contact the inner end of the pistons and thereby push the outer ends of the pistons toward contact with the earth formations.

26. The method of claim 23, wherein the pistons are fixed in a single predetermined position.

27. A completion system for use in a borehole drilled into earth formations to establish a fluid communication path between the interior of a pipe string and the formation traversed by the borehole, comprising:

a pipe string in the borehole having perforation devices positioned thereon adjacent a formation to be perforated, said perforating device having a perforating charge that will perforate into the formation;

detonation means on said perforation devices for

initiating the perforating charge, said detonation means being activated in response to a pressure wave within said pipe string; and

means for generating a pressure wave within said pipe string.

28. A method of opening a fluid communication path between a pipe string in a borehole and an earth formation traversed by the borehole, comprising the steps of:

positioning detonation charges on the pipe string so that an opening in the wall of the pipe string occurs upon detonation of the charges;

positioning the pipe string in the borehole with the detonation charges aligned with a selected formation; and

after running the detonation charges into the borehole on the pipe string, in a separate operation generating a pressure wave in the pipe string to activate the detonation charge.

29. A method of completing a borehole traversing earth formations, comprising the steps of:

installing detonating devices on a casing pipe string;

setting the casing pipe string in the borehole;

running production tubing into the casing pipe string, the interior bore of said production tubing being at a pressure below the formation pressure; and

activating said detonating devices by generating a shock wave in said production tubing to open said casing pipe to said formation.

30. The method of claim 29, further including packing off an annular space between the production tubing and the casing pipe above the detonating devices.

31. A completion system for use in a borehole drilled into earth formations, substantially as hereinbefore described with reference to the accompanying drawings.

32. A method for perforating an earth formation, substantially as hereinbefore described with reference to the accompanying drawings.

33. A method for perforating a borehole drilled into earth formations, substantially as hereinbefore described with reference to the accompanying drawings.

34. A method of opening a fluid communication path between a pipe string in a borehole and an earth formation, substantially as hereinbefore described with reference to the accompanying drawings.

35. A method of completing a borehole, substantially as hereinbefore described with reference to the accompanying drawings.